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Mapping the evolution of neuroscience research: scientific collaboration, thematic structure, and emerging research frontiers

Sofiyanita Sofiyanita*), Zona Octaria
Universitas Islam Negeri Sultan Syarif Kasim, Pekanbaru, Indonesia

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ABSTRACT

Neuroscience has matured into a large, multidisciplinary field whose rapid growth has fragmented it into many loosely connected subdomains, making its intellectual and social structure difficult to grasp through narrative review alone. This study maps the evolution of neuroscience research in terms of publication output, scientific collaboration, thematic structure, and emerging frontiers. A bibliometric analysis was conducted on 2,710 English-language articles exported from Scopus (1973–2026; snapshot 29 August 2026). Performance analysis and science mapping were performed, and co-authorship, keyword co-occurrence, and citation networks were visualized in VOSviewer. Data were audited and conservatively cleaned; author keywords were normalized and a publisher subject-collection prefix was documented and neutralized. The corpus accumulated 140,375 citations (mean 51.8 per document) and showed non-linear growth: a high-impact wave in 2005–2009 and a second, larger expansion from 2022 onward. Collaboration was near-universal (91.7% multi-authored; mean 6.25 authors/document) yet the co-authorship network was highly fragmented into small, weakly connected communities. Keyword co-occurrence revealed a neuroscience-centred structure organized around neurogenesis/neural-stem-cell biology, systems and behavioural neuroscience, and a cell-biology/organoid axis; temporal mapping showed a shift from classical adult-neurogenesis anatomy toward organoid- and cell-biology-driven, methods-intensive research. Neuroscience remains anchored in a strong disciplinary core while expanding unevenly toward organoid technologies and, more peripherally, toward learning and educational neuroscience; chemistry education was not identified within the corpus on the indicators used, pointing to a possible under-explored interface rather than a demonstrated gap. Findings describe bibliometric patterns within this Scopus-defined corpus and are descriptive rather than confirmatory.

Corresponding Author:

Sofiyanita Sofiyanita,
Universitas Islam Negeri Sultan Syarif Kasim, Pekanbaru, Indonesia
Email: sofiyanita@uin-suska.ac.id

Introduction

Neuroscience has evolved from a set of loosely related nineteenth- and twentieth-century inquiries into brain and behaviour into one of the most active multidisciplinary research programmes in contemporary science. It now integrates molecular and cellular biology, developmental and systems neuroscience, cognitive science,

computation, and bioengineering, and increasingly draws on stem-cell biology and tissue-engineering platforms such as organoids. This breadth is a strength, but it also makes the field's overall structure difficult to perceive from within any single sub-specialty.

As the field has grown, its questions have spread outward from cellular mechanisms toward cognition, learning, behaviour, and, more recently, technology and translational application. Adult neurogenesis and neural-stem-cell biology opened durable lines of enquiry into brain plasticity and repair (Ming & Song, 2011), while the advent of human pluripotent-stem-cell models and cerebral organoids has created powerful in-vitro systems for studying human brain development and disease (Lancaster et al., 2013; Lancaster & Knoblich, 2014). In parallel, sustained interest in the neural basis of cognition, learning, and even the gut–brain relationship has widened the interfaces between neuroscience and adjacent disciplines (Mayer et al., 2014).

This rapid expansion carries a cost: the literature has become voluminous and fragmented across many subdomains, journals, and research communities. Individual researchers can track their own niche, but the discipline as a whole lacks an easily legible map of how its themes relate, how collaboration is organized, and where the field is heading. Traditional narrative reviews, however expert, cannot fully capture structure at this scale, and they are vulnerable to selection bias in which literature is surveyed.

Bibliometric analysis addresses precisely this problem. Building on the long tradition of statistical bibliography (Pritchard, 1969; Broadus, 1987), and by applying quantitative methods to publication and citation metadata, it can reveal a field's intellectual structure, patterns of collaboration, thematic clusters, and their evolution over time, thereby complementing meta-analysis and structured reviews with a measure of objectivity (Zupic & Čater, 2015; Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021). Science-mapping techniques co-authorship, co-word (Callon et al., 1983), citation, co-citation (Small, 1973), and bibliographic coupling (Kessler, 1963) make it possible to aggregate the judgements of thousands of authors into interpretable maps of a discipline (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011). Bibliometric approaches have been applied across many biomedical and behavioural specialties, and neuroscience itself has begun to be examined scientometrically for instance, in national-level mapping of neuroscience impact (Andersen, Krogsgaard, Engel, & Schneider, 2018) and in analyses of specific subfields. Software such as VOSviewer (van Eck & Waltman, 2010) and the bibliometrix R-package (Aria & Cuccurullo, 2017) has made large-scale mapping widely accessible.

Yet a broad, structural mapping of neuroscience as a whole one that simultaneously traces its productivity, its collaboration architecture, its thematic organization, and its temporal evolution across a multi-decade corpus remains comparatively scarce. Existing scientometric work on the field has largely been confined to national-level impact assessment (Andersen et al., 2018) or to narrow clinical and methodological niches rather than the disciplinary core, and few studies simultaneously combine productivity, collaboration architecture, thematic structure, and temporal evolution across a multi-decade corpus. Fewer still ask, rather than assume, how peripheral interfaces such as learning and education relate to that core. This study addresses that gap by mapping a 54-year, 2,710-document neuroscience corpus and examining not only its dominant themes but also whether learning, cognitive neuroscience, and science education constitute core themes, emerging frontiers, or merely sporadic mentions. This neuroscience–education relationship is examined as an exploratory sub-question within the thematic mapping (RQ4), not as a primary objective of the study.

Accordingly, this study makes three contributions: it provides an integrated, data-grounded map of neuroscience productivity, collaboration, and conceptual structure over more than five decades; it traces the field's thematic evolution and identifies emerging frontiers; and it treats the neuroscience–learning–education interface analytically rather than assuming its centrality, while documenting methodological pitfalls publisher subject tags and author-name homonyms that any large Scopus-based mapping of this field must confront. Four research questions guide the study. RQ1: How has neuroscience research evolved over time in terms of publication output and scientific impact? RQ2: What are the patterns and structures of scientific collaboration among researchers? RQ3: What are the major research themes and conceptual clusters that characterize the field's intellectual structure? RQ4: How have research themes evolved over time, and which emerging topics are becoming research frontiers?

Method

Research design

This study employs a bibliometric research design combining performance analysis (publication and citation metrics) with science mapping (relational analysis of authors, keywords, and citations), following established

guidelines for conducting bibliometric analyses (Zupic & Čater, 2015; Donthu et al., 2021). The design is descriptive and exploratory rather than confirmatory.

Data source, search strategy, and corpus

Bibliographic metadata were obtained from Scopus, chosen for its broad coverage of peer-reviewed neuroscience literature and its structured, exportable metadata. The complete record set was exported as a CSV file containing 45 metadata fields, including authors and author identifiers, titles, publication years, source titles, citation counts, author and index keywords, affiliations, and cited references, as a snapshot dated 29 August 2026. The exported corpus comprised 2,710 documents spanning 1973–2026. Because the objective was to characterize the neuroscience core rather than a narrow niche, the full exported record set was retained as the unit of study, and no thematic sub-selection was performed. The retrieval that produced this export is reported here in full to support reproducibility: **[Author to insert the exact Scopus query string, the search fields used (e.g., TITLE-ABS-KEY / SRCTYPE), and the year, document-type, and language limiters applied to generate the 2,710-record export].** All records returned by this query were exported and retained without further thematic filtering.

Inclusion, exclusion, and data cleaning

The corpus was homogeneous in document type and language: all 2,710 records were English-language journal articles, so no records were excluded on those grounds. Cleaning was deliberately conservative and fully documented. Exact duplicates were absent (0 duplicated EIDs; 0 duplicated non-null DOIs), and two title-level near-duplicates were verified as distinct records and retained. Missing values were handled field-wise rather than by deleting records: abstracts, citation counts, and source titles were complete, whereas author keywords were absent for 383 documents (14.1%), so keyword co-occurrence was computed on the 2,327 documents that carried author keywords. Author keywords were lower-cased and whitespace-normalized, and unambiguous singular/plural variants were merged (e.g., *stem cell* with *stem cells*). Two data-quality issues were explicitly neutralized: 205 documents carried keywords prefixed "cp:" that originate entirely from Cell Reports and Cell Reports Methods and represent a Cell Press subject-collection tag rather than author keywords (de-emphasized in interpretation); and high-frequency surname–initial author names (e.g., Wang Y., Zhang Y.) that Scopus does not disambiguate reliably were treated cautiously, with author-level results reported by citation impact rather than raw name frequency and no speculative merging performed.

Bibliometric analysis, visualization, and research questions

Performance analysis covered annual publication output, annual and cumulative citations, average citations per document, leading sources, and the most-cited documents and authors; because 2025–2026 documents have had limited time to accrue citations, these years are annotated and excluded from citation-impact comparisons while retained for production counts. Country participation was extracted from affiliation strings using presence-based matching and is reported as approximate. Science mapping and visualization were performed in VOSviewer (van Eck & Waltman, 2010), which constructs bibliometric networks using association-strength normalization and a clustering algorithm; co-authorship, keyword co-occurrence, and citation networks were mapped, and overlay visualizations encoding the average publication year of each item were used to analyze thematic evolution. Cited references were available for 96.6% of records, so co-citation and bibliographic-coupling analyses are feasible; because they were not among the mapped networks here, they are identified as an extension rather than reported. The four research questions structure the Results and Discussion: RQ1 through publication and citation trends, RQ2 through collaboration and source analysis, RQ3 through keyword clustering, and RQ4 through temporal overlay mapping. To support reproducibility, the network parameters are reported as follows: counting method = **[full/fractional]**; minimum keyword co-occurrence threshold = **[n]**, yielding **[n]** mapped keywords; minimum thresholds for the co-authorship and citation maps = **[n]**; and clustering resolution = **[default / value]**.

Results and Discussions

Dataset characteristics

The corpus comprises 2,710 journal articles published between 1973 and 2026, drawn from 658 distinct sources and involving 16,884 author appearances. The documents accumulated 140,375 citations, with a mean of 51.8 and a median of 18 citations per document; 201 documents (7.4%) were uncited at the snapshot date (Table 1). The large gap between mean and median indicates a strongly right-skewed citation distribution a small number of foundational papers carry a disproportionate share of impact, a pattern typical of mature scientific fields and one that motivates the citation analysis below.

Table 1. <Dataset characteristics.>

Characteristic	Value
Documents	2,710
Document type / language	Article (100%) / English (100%)
Publication span	1973–2026 (54 years)
Total citations (snapshot)	140,375
Mean / median citations per document	51.8 / 18
Uncited documents	201 (7.4%)
Distinct sources	658
Author appearances (raw names)	16,884 (13,851 distinct strings)
Mean authors per document	6.25
Author-keyword instances	14,389 (documents with keywords: 2,327)
Records with cited references	96.6%

All values computed directly from the Scopus export. Distinct author strings are an upper bound before disambiguation.

Publication growth and scientific impact (RQ1)

Publication output grew non-linearly across the study period (Figure 1; Table 2). After a sparse foundational era (1973–1999: 96 documents, 3.5%), output surged during 2000–2009 (818 documents, 30.2%), peaking in 2009 (182 documents). This first wave was exceptionally high in citation density—average citations per document reached 145.0 in 2006 and 119.8 in 2005—before output consolidated through the 2010s (776 documents, 28.6%) and entered a second, larger expansion from 2020 onward (1,020 documents, 37.6%), with 190 documents in 2025 alone.

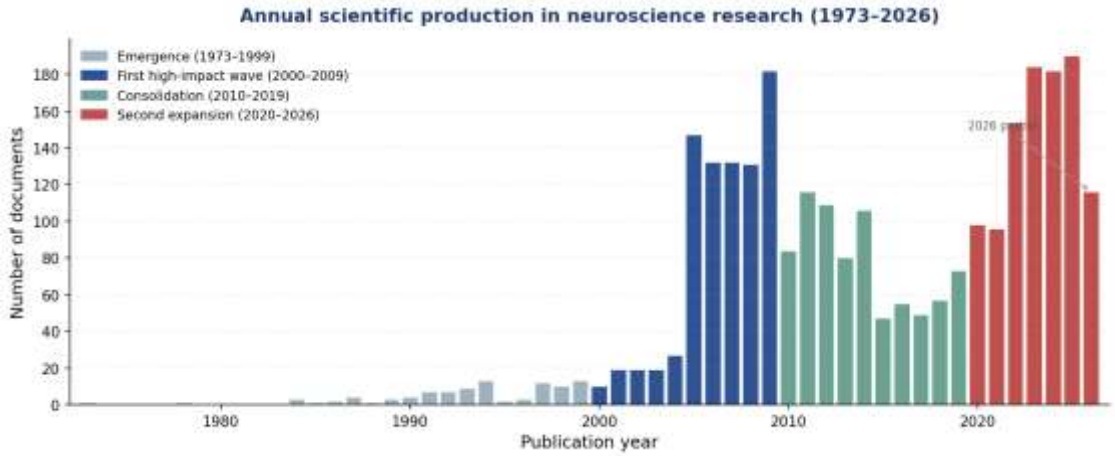

Figure 1. <Annual scientific production in neuroscience research (1973–2026), computed from the Scopus corpus. Colours mark the emergence (1973–1999), first high-impact wave (2000–2009), consolidation (2010–2019), and second expansion (2020–2026) periods; 2026 is a partial year.>

Interpreted against the field's history, this trajectory suggests two distinct engines of productivity. The 2005–2009 wave, with its very high citation density, coincides with the maturation of adult-neurogenesis and neural-stem-cell research and the arrival of foundational human-embryonic-stem-cell and spinal-cord-repair studies (Kawasaki et al., 2000; Keirstead et al., 2005; Menn et al., 2006); the most-cited documents of the corpus — including its largest-cited nodes (Van Sickle et al., 2005; Kirsch et al., 2005; Keirstead et al., 2005; Kawasaki et al., 2000) — cluster visibly in this period (Figure 2). The later expansion is dominated by organoid, cell-biology, and protocol literature (see 3.4–3.5). Crucially, the lower average citations in the most recent years reflect citation lag rather than declining influence; treating 2025–2026 impact figures as a real downturn would be a methodological error that any snapshot-based analysis must guard against (Donthu et al., 2021).

Table 2. <Publication output and citation impact by period, with representative years.>

Period / Year	Documents	Citations	Avg. cit./doc
1973–1999	96	—	emergence
2000–2009	818	—	first high-impact wave
2010–2019	776	—	consolidation
2020–2026	1,020	—	second expansion
2005	147	17,608	119.8
2006	132	19,138	145.0
2009	182	18,346	100.8
2019	73	2,287	31.3
2023	184	3,056	16.6
2025*	190	785	4.1
2026*	116	60	0.5

*2025–2026 citation averages reflect citation lag, not declining impact; retained for production counts, excluded from impact comparisons.

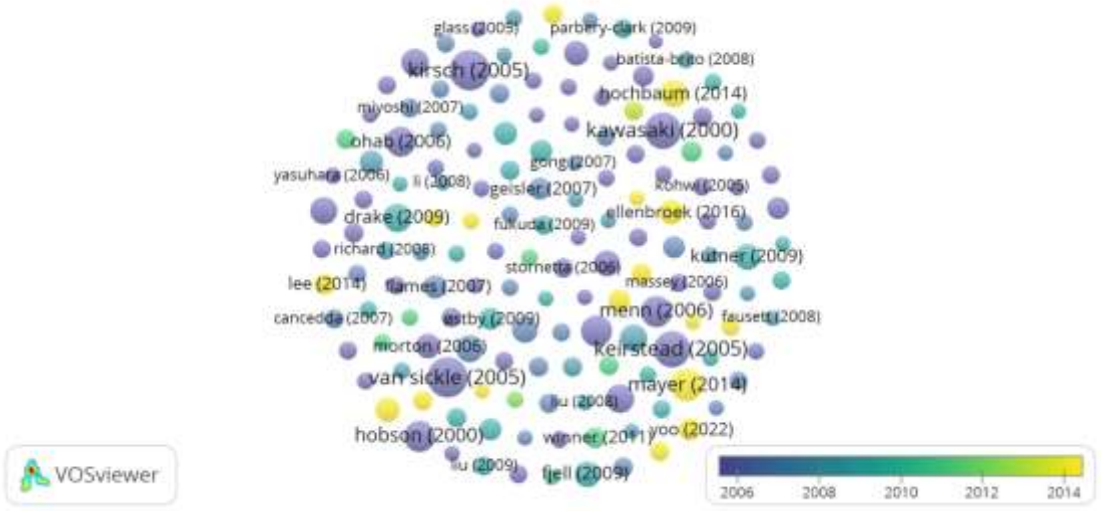

Figure 2. <Document citation map with temporal overlay (VOSviewer). Node size encodes citations received; the largest nodes (Van Sickle 2005, Kirsch 2005, Keirstead 2005, Kawasaki 2000) correspond to the most-cited publications and are concentrated in the 2000–2009 high-impact wave.>

Scientific collaboration and knowledge communities (RQ2)

Collaboration is near-universal: 91.7% of documents are multi-authored versus 8.3% single-authored, with a mean of 6.25 authors per document and a maximum of 98. Yet the author co-authorship network is highly fragmented (Figure 3): most authors are isolated nodes, with only a few small connected components for example, a group linking Okano, Alvarez-Buylla, and Rubenstein, and a triad of Kraus, Skoe, and Nicol.

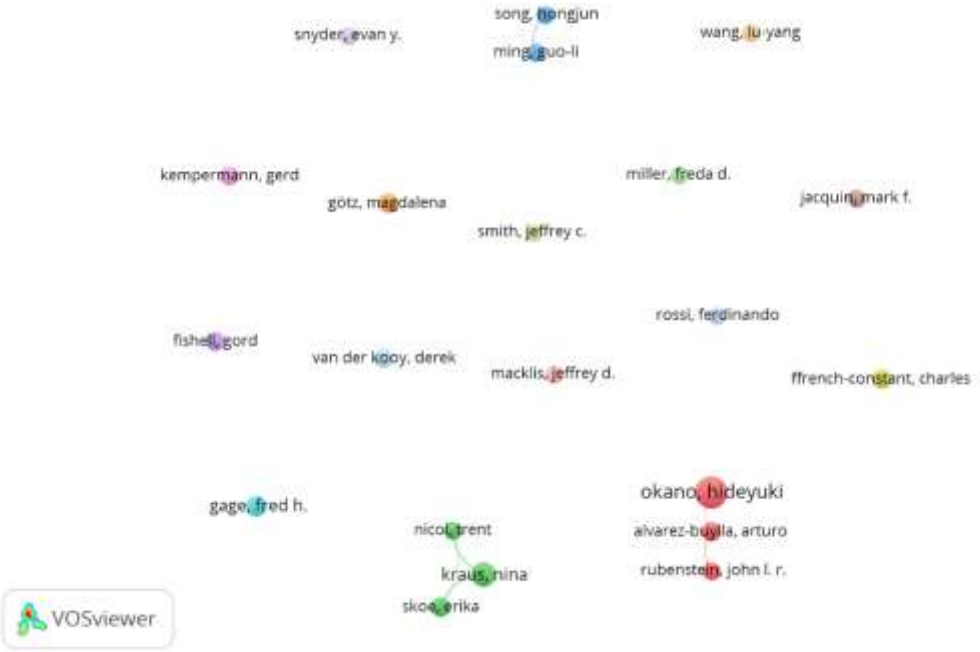

Figure 3. <Author co-authorship network (VOSviewer). The network is highly fragmented: most authors are isolated, with only small connected components (e.g., Okano–Alvarez-Buylla–Rubenstein; Kraus–Skoe–Nicol). Okano is the largest node.>

This coexistence of intense paper-level collaboration with a fragmented network is the most striking structural finding. Subject to confirmation with formal network statistics (e.g., component counts and modularity), the rendered co-authorship map suggests that neuroscience is organized into many small, weakly bridged communities rather than one cohesive core, consistent with a broad multidisciplinary field in which distinct sub-specialties (regenerative biology, systems physiology, auditory cognition, spinal-cord injury) recruit separate author sets. It also cautions against reading name-frequency "productivity" uncritically: in a globally distributed field, surname–initial homonyms distort raw counts, so citation-anchored measures are more trustworthy (Zupic & Čater, 2015). Reported this way (Table 3), the citation-leading authors Alvarez-Buylla, Fehlings, Götz, and Okanomap onto regenerative and developmental neuroscience, reinforcing that subfield's centrality; Okano is also the largest node in the co-authorship and author-citation maps (Figures 3 and 4).

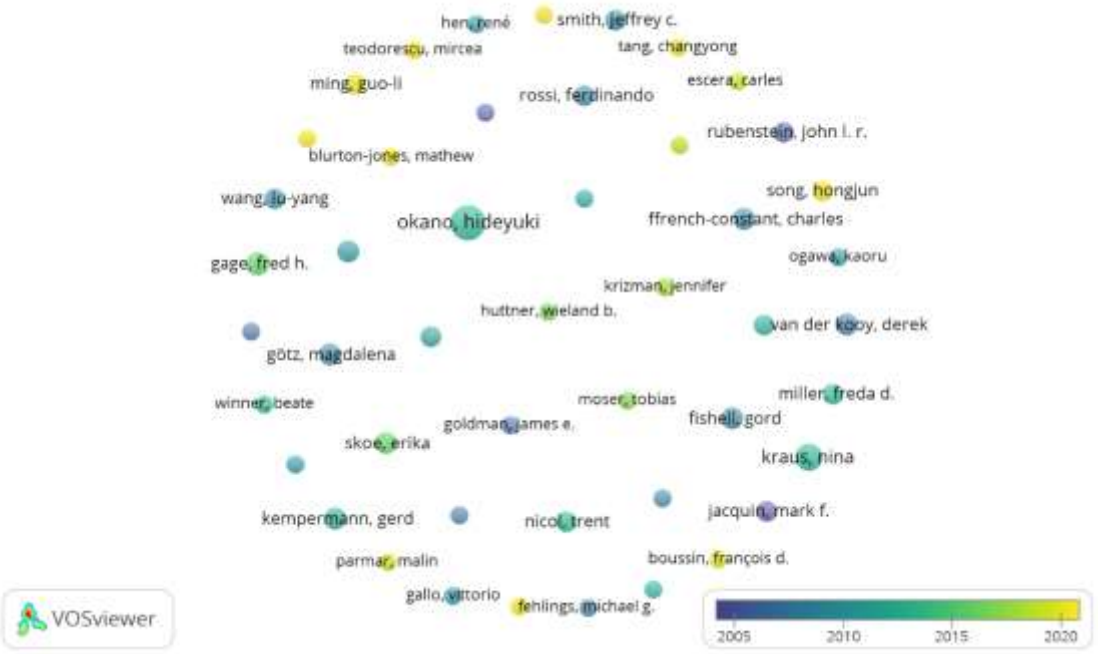

Figure 4. <Author citation map with temporal overlay (VOSviewer). Node size encodes citation impact and colour encodes average publication year; Okano is the most citation-influential node.>

Table 3. <Most citation-influential authors (homonym-robust).>

Author	Documents	Total citations
Alvarez-Buylla, A.	7	1,755
Fehlings, M. G.	5	1,601
Götz, M.	7	1,599
Okano, H.	18	1,542
Carmichael, S. T.	3	1,402
Kraus, N.	12	(productivity anchor)

Ranked by total citations to reduce homonym distortion; high-frequency surname–initial names excluded as unresolved homonyms.

Country participation, extracted from affiliations, is led by the United States (present in 1,278 documents), followed by Germany (289), the United Kingdom (262), Japan (248), China (206), Canada (185), France (144), and Italy (136), confirming a predominantly North-American and Western-European field with strong Japanese participation. Among sources (Table 4), Journal of Neuroscience alone accounts for roughly half of all citations, and the prominence of protocol venues (STAR Protocols, Journal of Visualized Experiments, Cell Reports Methods) signals the methods-intensive character of the recent literature a signal that recurs in the thematic analysis below.

Table 4. <Leading sources by publication output.>

Source	Documents	Citations
Journal of Neuroscience	500	70,960
European Journal of Neuroscience	237	13,653
Cell Reports	193	3,701
Neuroscience Research	143	4,668
STAR Protocols	134	923
iScience	125	1,365
Journal of Visualized Experiments	103	1,782

Thematic structure and conceptual clusters (RQ3)

Keyword co-occurrence analysis (Figure 5; Table 5) yields a clearly structured conceptual map with neuroscience as the dominant central node (482 occurrences), surrounded by neurogenesis, neural stem cells, cell biology, and organoids. The dominance of neuroscience indicates that the field remains anchored in its core disciplinary identity while extending strongly into stem-cell and tissue-model biology.

Table 5. <Most frequent author keywords (normalized; publisher "cp:" tags excluded).>

Keyword	Freq.	Keyword	Freq.
neuroscience	482	cell culture	58
stem cells (merged)	236	brainstem	55
neurogenesis	156	cell differentiation	51
neural stem cells (merged)	143	adult neurogenesis	46
cell biology	113	subventricular zone	43
development	63	brain	38
differentiation	61	organoids	36
hippocampus	60	microscopy	36

The network resolves into interpretable clusters, named from the keywords that actually co-occur. A neurogenesis/neural-stem-cell cluster (neurogenesis, neural stem cells, differentiation, neuron, glia, oligodendrocyte, transplantation, dentate gyrus, subventricular zone) represents the developmental and regenerative core. A systems and behavioural cluster (mouse, brain, hippocampus, plasticity, brainstem, learning, pain, spinal cord, cognitive neuroscience, fMRI) is where learning and cognitive neuroscience appear as peripheral bridging terms. A cell-biology and organoid cluster (stem cells, cell biology, cell culture, cell differentiation, organoids, microscopy, model organisms) represents the methods- and model-oriented axis. Interpreting the remaining groupings requires caution: much of their content derives from Cell Press subject-collection tags rather than author-chosen keywords, a publisher-indexing effect that could otherwise be mistaken for an organic research theme documenting and neutralizing such artifacts is an under-appreciated but essential step in keyword-based science mapping (Cobo et al., 2011).

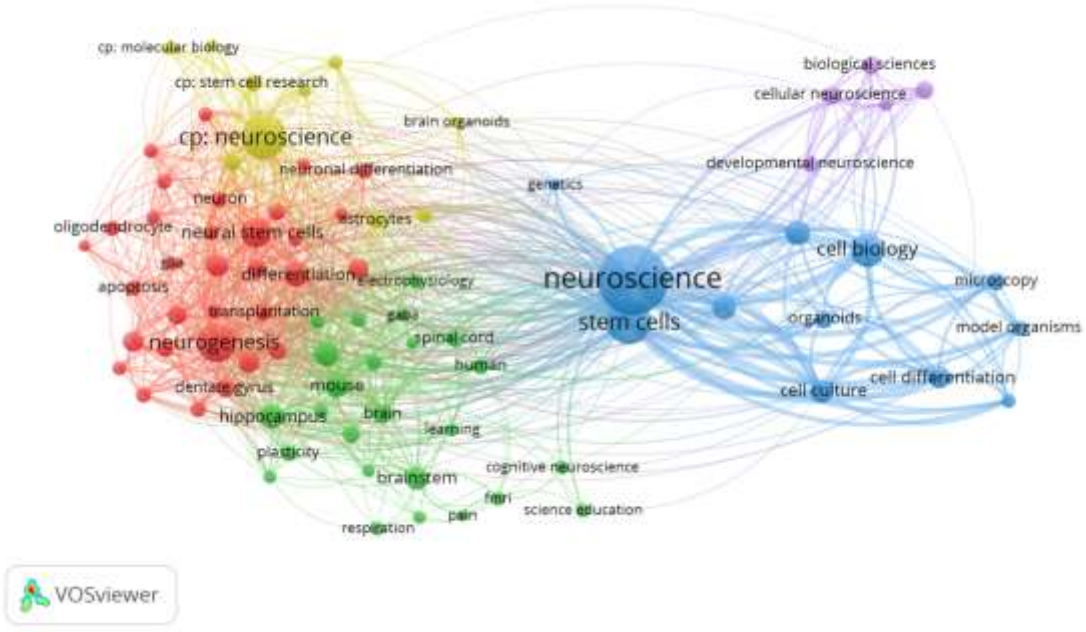

Figure 5. <Author-keyword co-occurrence network (VOSviewer). neuroscience is the central node; clusters correspond to the neurogenesis/neural-stem-cell core, the systems/behavioural periphery, the cell-biology/organoid axis, and publisher-derived groupings.>

Thematic evolution and emerging frontiers (RQ4)

Overlay mapping of the average publication year of each keyword (Figure 6; Table 6) reveals a coherent temporal gradient rather than a simple recency effect. Foundational terms cluster in the mid-to-late 2000s—oligodendrocyte (2006.8), immunohistochemistry (2007.1), migration (2007.5), glia (2008.5), apoptosis and cerebellum (2009.0), dentate gyrus and subventricular zone (2009.1)—reflecting an early emphasis on the anatomy and cellular mechanisms of adult neurogenesis. The most recent terms concentrate around 2022–2023: microscopy (2022.1), model organisms (2022.3), cell biology (2022.7), organoids (2022.9), cellular neuroscience (2023.0), and brain organoids (2023.3), together with iPSCs (2021.9). Persistent intermediate-year themes such as neurogenesis, hippocampus, and differentiation form the backbone linking the two eras.

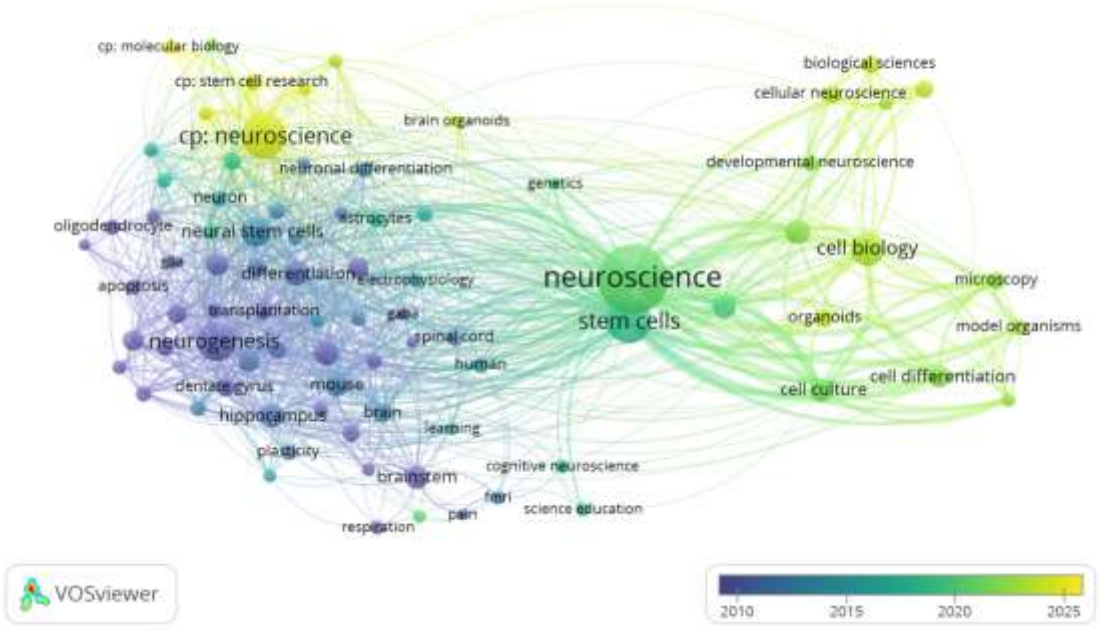

Figure 6. <Overlay (temporal) visualization of the keyword co-occurrence network (VOSviewer). Node colour encodes the average publication year (~2010 purple to ~2025 yellow), illustrating the shift from foundational neurogenesis themes toward organoid- and cell-biology-driven research.>

On the basis of recency of average publication year — a necessary but not sufficient indicator of a research front — the most prominent recency-based candidate frontier is therefore the organoid and cell-biology axis, reflecting the field's turn toward human-relevant in-vitro models and methods (Lancaster & Knoblich, 2014; Lancaster et al., 2013); the prominence of protocol journals (3.3) corroborates this methods-intensive turn. This frontier offers high-opportunity research space where organoid models could be linked to functional and cognitive readouts.

Table 6. <Foundational versus emerging themes (average publication year; keywords with ≥15 occurrences).>

Foundational (≤2009)	**Avg. yr**	**Emerging (≥2022)**	**Avg. yr**
oligodendrocyte	2006.8	microscopy	2022.1
immunohistochemistry	2007.1	model organisms	2022.3
migration	2007.5	cell biology	2022.7
glia	2008.5	organoids	2022.9
apoptosis / cerebellum	2009.0	cellular neuroscience	2023.0
dentate gyrus	2009.1	stem cells research	2023.2
subventricular zone	2009.1	brain organoids	2023.3

The neuroscience–learning–education interface (RQ4)

A specific aim was to test rather than assume whether learning, cognitive neuroscience, and science education constitute core themes or peripheral frontiers. The data support the latter (Table 7). Learning appears 108 times across many variants, but the generic term "learning" occurs only 17 times (average 2015) and its recent growth

is computational (deep learning, machine learning) rather than educational. Cognitive neuroscience (20 occurrences, average 2018) functions as a genuine but modest bridge between the biological core and behavioural research consistent with long-standing arguments that connections between neuroscience and cognition/education must be built through mechanism-level dialogue rather than assumed (Ansari & Coch, 2006; Goswami, 2006). Education-related terms total roughly 138 occurrences but are scattered across small variants (science education 21, STEM education 13, educational neuroscience 8), making education an emerging, still-consolidating interface (Sigman, Peña, Goldin, & Ribeiro, 2014; Carew & Magsamen, 2010) rather than a mature component of the core.

Critically, chemistry and chemistry education are effectively absent: zero author-keyword and zero abstract occurrences of chemistry education, with "chemistr-" appearing only as laboratory methods (immunohistochemistry, biochemistry). Rather than forcing this absence into a central narrative, it is best read as a genuine, under-explored gap an interface that, if pursued, would need to be built deliberately and mechanistically rather than described as an existing trend.

Table 7. <Emerging frontiers and peripheral interfaces.>

Theme / interface	**Signal (occurrences)**	**Status**
Organoids / brain organoids	36 (rising, avg 2022–2023)	Emerging frontier (strong)
Cell biology / model organisms	113 / 26 (avg 2022–2023)	Emerging frontier (strong)
iPSCs	15 (avg 2021.9)	Emerging frontier
Cognitive neuroscience	20 (avg 2018)	Peripheral bridge
Learning (generic)	17 (avg 2015)	Peripheral / mixed with computation
Science / STEM education	21 / 13	Emerging, peripheral
Educational neuroscience	8	Under-explored
Chemistry education	0	Not identified in corpus

Methodological considerations and limitations

Several limitations bound these findings. The corpus derives from Scopus only, so coverage may differ from Web of Science or PubMed; citation counts reflect a single export date and under-represent recent years by construction; author-name homonyms limit person-level productivity ranking despite the citation-anchored mitigation used here; publisher subject tags and the 14.1% of documents lacking author keywords constrain the keyword map; and country participation, parsed from affiliation strings, is indicative rather than exact. Finally, although the reference data would support co-citation and bibliographic-coupling maps, these intellectual-structure analyses were not performed and are noted only as an extension, so that no unsupported results are introduced.

Conclusions

This bibliometric mapping of 2,710 Scopus-indexed neuroscience articles (1973–2026) answers the four research questions as follows. RQ1: neuroscience research has grown non-linearly, with a high-impact wave in 2005–2009 and a larger, methods-intensive expansion from 2022 onward; recent-year citation figures must be read in light of citation lag. RQ2: collaboration is near-universal at the article level yet the co-authorship network is fragmented into many small communities, with regenerative and developmental neuroscientists (Alvarez-Buylla, Götz, Okano, Fehlings) among the most citation-influential. RQ3: the intellectual structure is centred on neuroscience and organized around a neurogenesis/neural-stem-cell core, a systems/behavioural periphery, and a cell-biology/organoid axis. RQ4: themes have evolved from classical adult-neurogenesis anatomy toward organoid- and cell-biology-driven research, with cognitive neuroscience and education/learning as peripheral, emerging interfaces and chemistry education not identified in the corpus. These conclusions describe bibliometric patterns within the Scopus-indexed corpus analysed here rather than the direction of neuroscience as a whole.

Overall, neuroscience remains anchored in a strong disciplinary core while expanding unevenly toward human-relevant in-vitro models and, more tentatively, toward cognitive and educational interfaces. Future work should add co-citation and bibliographic-coupling maps (feasible from the available references) to reveal the

field's foundational base and research fronts; cross-validate with Web of Science and PubMed and reconcile author identifiers; deepen the temporal analysis with trend-topic and thematic-evolution modelling; and pursue the corpus-identified organoid trend and the deliberately-built neuroscience–education interface treating the absent neuroscience–chemistry-education link as a candidate area for future, mechanism-grounded research.

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